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Validation and Improvement of CERES Surface Radiation Budget Algorithms: Extension of Dusty and Cloudy Scenes

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Our main task was to validate and improve the generation of surface long wave fluxes from the CERES TOA window channel flux measurements. We completed this task successfully for the clear sky fluxes in the presence of aerosols including dust during the first year of the project. The algorithm we developed for CERES was remarkably successful for clear sky fluxes and we have no further tasks that need to be performed past the requested termination date of December 31, 2004. We found that the information contained in the TOA fluxes was not sufficient to improve upon the current CERES algorithm for cloudy sky fluxes. Given this development and given our success in clear sky fluxes, we do not see any reason to continue our validation work beyond what we have completed. Specific details are given below.

Generation of CERES Surface Longwave Fluxes and Their Validation.

The empirical parameterizations for the retrieval of long wave surface radiation budget directly from the observed top of atmosphere (TOA) CERES fluxes and other meteorological variables follows the physical principles described in Inamdar and Ramanathan (1997). This parameterization has been revised and extended during 2001 to cover the global land surfaces. The Algorithm Theoretical Basis Document (ATBD) is available through the Web site http://asd-www.larc.nasa.gov/ATBD/ATBD.html. Revisions implemented to the procedures are described in the Quality Summary Document for TRMM CERES SSF Edition 2B products available at http://eosweb.larc.nasa.gov/PRODOCS/ceres/SSF/Quality_Summaries/ssf_surface_flux_trmm_ed2B.html. These have been implemented in the production and archival of surface radiation budget in the subsequent versions of the CERES data products. We also acquired ground measurements of long wave radiation budget data from a vast network of land stations around the globe including the Central and Extended Site Facilities of the Atmospheric Radiation Measurement Program (ARM), and have been performing validation studies by matching the CERES footprints with in situ data. The results have been presented at the various CERES Science team meetings and also reported in peer-reviewed Journal articles (Inamdar et al, 2004). A separate Journal article on validation studies is under preparation at present.

Validation of Dust Forcing:

This study uses data collected from the Clouds and the Earth's Radiant Energy System (CERES) and the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments to determine Saharan dust broadband shortwave aerosol radiative forcing over the Atlantic Ocean near the

African coast (15°N to 25°N, 45°W to 15°W). We derive the clear-sky aerosol forcing directly from these data, without requiring detailed information about the aerosol properties that are not routinely observed such as chemical composition, microphysical properties, and their height variations. We determine the diurnally averaged Saharan dust radiative forcing efficiency (*i.e.*, broadband shortwave forcing per unit optical depth at 550 nm, W $m^{-2}\tau_a^{-1}$) juxtaposing two extreme seasons: the high dust months (June to August, JJA) and the low dust months (November to January, NDJ). We find that the top-of-atmosphere (TOA) diurnal mean forcing efficiency is -35 ± 3 W $m^{-2}\tau_a^{-1}$ for JJA, and -26 ± 3 W $m^{-2}\tau_a^{-1}$ for NDJ. These efficiencies can be fit by reducing the spectrally varying aerosol single-scattering albedo such that its value at 550 nm is reduced from 0.95 ± 0.04 for JJA to about 0.86 ± 0.04 for NDJ. The lower value for the low dust months might be influenced by biomass burning aerosols that were transported into the study region from Equatorial Africa. Although the high dust season has a greater (absolute value of the) TOA forcing efficiency, the low dust season may have a greater surface forcing efficiency. Extrapolations based on model calculations suggest the surface forcing efficiencies to be about -65 W $m^{-2}\tau_a^{-1}$ for the high dust season versus -81 W $m^{-2}\tau_a^{-1}$ for the low dust season. These observations indicate that the aerosol character within a region can be readily modified, even immediately adjacent to a powerful source region such as the Sahara.

Atmospheric Greenhouse Effect from ERBE, TRMM and TERRA Satellites

We have analyzed satellite data spanning over a decade to estimate the atmospheric greenhouse effect. The earlier study reported in Inamdar & Ramanathan (1998) examined the ERBE data (1985-1989) on seasonal to inter-annual time scales to determine the interactions between the atmospheric greenhouse effect, surface temperature and tropospheric water vapor to assess the water vapor feedback. The most recent data from TRMM (1998) and TERRA (2000 – 2001) satellites has permitted us to extend the analysis and examine the inter-decadal scale variations to look for signals of long-term climate change. Results have been reported at the various CERES Science team meetings.

- **Absorption in the Continuum and Vibrational-rotational to Pure Rotational Bands from CERES**

The new channel configuration of the CERES instrument with its 8 – 12 micron channel has afforded us a unique opportunity to observe the atmospheric greenhouse effect segregated into

contributions from the continuum and vibrational-rotational to pure rotational absorption bands. Correlation of the respective components of the atmospheric greenhouse effect with the appropriately scaled water vapor amounts using the updated and latest SSF (Single Satellite Footprint) data has revealed that absorptivity inferred from the CERES observations is consistent with the underlying quantum physics. Further, the separation into the window and non-window components has been found to yield valuable insights into the sensitivity to the vertical structure of tropospheric water vapor and also the horizontal transport of water vapor in the atmosphere. These results have been reported in a recent paper to appear in a book published by Cambridge University Press to be published in 2005 under the title: Frontiers in Climate Modeling.

- **Radiative Forcing due to Mineral Dust Aerosol in the IR region**

Mineral aerosols play a key role in climate forcing. However there are large uncertainties associated with shape, size and distribution of these aerosols and determination of even the sign of net forcing is difficult. MODIS on TERRA along with CERES has given us the first opportunity to estimate the forcing directly from observations. We made some preliminary estimates of such a forcing over the Arabian Sea and results have been reported in meetings. The estimates of forcing have been found to be consistent with other published studies and offer great promise for extending the study into other regions like Sahara.

List of Publications Funded by the NASA/CERES contract

V. Ramanathan and A. Inamdar: The Radaitive forcing due to clouds and water vapor. IN Frontiern in Climate Modeling, Cambridge University Press, 2005.

Inamdar, A. K., V. Ramanathan, and N. G. Loeb, 2004: Satellite observations of the water vapor greenhouse effect and column longwave cooling rates: Relative roles of the continuum and vibration-rotation to pure rotation bands. *J. Geophys. Res., 2004,109.*

Li, F., A. M. Vogelmann and V. Ramanathan, 2004: Dust Aerosol Radiative Forcing Measured from Space Over the Western Africa. Journal of Climate, 17(13), 2558-2571.

Inamdar, A. K., and D. P. Kratz, 2003: Retrieval and validation of the surface longwave radiation budget from CERES. *EOS Supplements, AGU Fall meeting, San Francisco, Dec 2003.*